Chapter 2: The California Power Grid

2.1 Transmission Lines

For the purpose of this report, we define transmission lines as electric power lines with a voltage class of 34kV or higher. The California Energy Commission published a map of the major (above 230 KV) transmission lines in California, which is shown in Figure 2.1 (see California Energy Commission (1999). The lines in this map represent circuit miles. Thus, several circuit lines could be present on one structure, and several structures could be present on the same corridor.

We contracted with Impact Assessment, Inc. (IAI) to obtain a better understanding of the land use, population characteristics and housing patterns in areas near transmission lines. Using a geo-coded database of all transmission lines obtained from the California Energy Commission, IAI sampled 200 transmission line segments of one mile in length for each of five voltage categories. Figure 2.2 shows the samples taken. Within 500 feet of each side of the transmission line, IAI determined the distribution of land use and selected census variables using data from the U.S. Geological Survey/EPA and the U.S. Census Bureau.[2] Following is a summary of the IAI report (the full report is available as Appendix G).

Methods

The California Energy Commission is developing a geo-coded statewide map of transmission lines in California. Even though the map is still under development, the staff of the Commission was kind enough to make it available for this project. Information for transmission lines included ownership of lines (represented by line color), and voltage (represented by line weight).

All records which were lines or polylines and had a voltage described in the layer name were selected. The transmission lines were sorted into 6 voltage categories (34-59 kV, 60-92 kV, 110-161 kV, 220-287 kV, 345-500 kV, and 500 kV DC). In each voltage category, transmission lines were segmented into lengths of exactly 1 mile, limited by the accuracy of the micro-processor and the scale of the power line coverage. Two hundred segments were then randomly chosen from each of the six power line categories.

Residential land use data for the state was obtained from the Geographic Information Retrieval and Analysis System (GIRAS). This land use data was collected by the U.S. Geological Survey and converted into a GIS coverage by the U.S. EPA. Land use was mapped using the Anderson land use coding system. Census data at the block group level was used from the *Census of Population and Housing, 1990: Summary Tape File 3 for California* (Bureau of Census, 1990).

[2] Since census data were available on the block group level only, the actual areas on which these estimates were based were likely somewhat larger than the 5,500 feet x 1,000 that was examined.

Figure 2.1: Map of Major California Transmission Lines

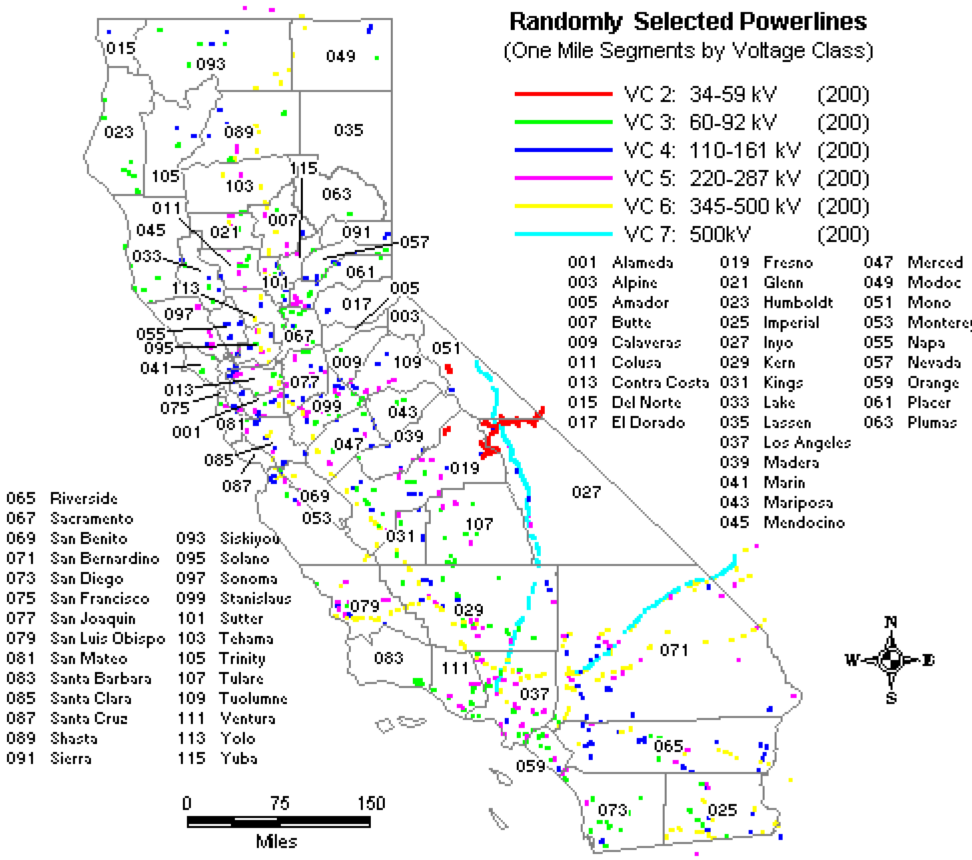

Figure 2.2: Samples of Transmission Lines Taken for the GIS Analysis

We used the following variables from this file: Persons (100% count), Black race, Hispanic origin, median household income in 1989, and median value (of owner-occupied units). The percent Black and Hispanic were computed by dividing the number of Blacks and Hispanics by the 100% population count for each block group (method described below). The statewide block group geographic coverage was created by combining county-level (1:100,000 scale) polygons that were derived from the Census Tiger database.

The chosen one-mile transmission line segments were buffered in ArcView to a distance of 500 feet. The polygons resulting from the buffering process were overlaid with the GIRAS land use layer and the statewide layer of census data block group boundaries. For the census data, population distributions were assumed to be homogeneous throughout the block group. The block group area which overlapped the 500 ft. buffer polygon for each power line segment was computed. This percentage area was multiplied by the total population count and the number of Blacks and Hispanics for each block group to get an estimate of the percentage Black and Hispanic for each buffered polygon. For the median household income and property values, an average was computed for each variable based on weighting the estimated population in the overlaid block group area by the average income and property value for that block group.

The percentage land use for each voltage category was computed by summing all the land use polygons, which overlapped the 500 ft. buffer for each power line segment. Land use and census data were summarized for each voltage category.

Results

There was a total of 43,142.9 miles (or 227,794,646.5 feet) of statewide transmission lines in the database. Table 2.1 shows the distribution of the transmission lines by voltage class. The largest class was 60-92 kV with 14,840.5 miles (34.4% of the database). Table 2.2 shows the distribution of transmission lines by ownership class. The largest ownership category was Pacific, Gas, and Electric, with 19,116.4 miles of lines, or 44.3% of the database.

Table 2.1: Length of Transmission Lines by Voltage Class

VOLTAGE CLASS	LENGTH	
	FEET	MILES
2 (34-59 kV)	1,117,033.4	211.6
3 (60-92 kV)	78,357,914.5	14,840.5
4 (110-161 kV)	54,659,570.3	10,352.2
5 (220-287 kV)	66,688,398.4	12,630.4
6 (345-500 kV)	23,685,831.4	4,486.0
7 (500 kV)	3,285,898.5	622.3
Total	227,794,646.5	43,142.9

Table 2.3 shows the distribution of land use for each voltage class. The largest land use was shrub and brush rangeland, with 30.1% of the total land area. The second largest land use category was evergreen forest land, with 23.5% of the total land area. Voltage class 500 kV had the largest percentage of land use in shrub and brush rangeland, with 54.9% of the total land area for that voltage class. Voltage class 34-59 kV had the largest land use for evergreen forest land (41.0%) and for shrub and brush tundra (17.1%). Residential land use in the vicinity of transmission lines is fairly rare, ranging from 6 to 8.4% for the intermediate voltage classes and being negligible for the others. Overall, developed land uses (shaded in the table) add to less than 10% of the whole transmission line system.

Table 2.2: Length of Transmission Lines by Ownership

OWNERSHIP CLASS	LENGTH	
	FEET	MILES
Bonneville Power Administration	319,889.9	60.6
Burbank Public Service Dept.	56,166.7	10.6
California – Pacific Utilities Company	514,047.3	97.4
Comision Federal de Electricidad	200,979.6	38.1
California – Oregon Transmission Project	1,877,411.5	355.6
California Department of Water Resources	188,605.8	35.7
Glendale Public Service Department	57,411.2	10.9
Imperial Irrigation District	7,439,512.3	1,409.0
Intermountain Power Agency	901,310.6	170.7
Los Angeles Dept. of Water and Power	13,456,485.9	2,548.6
Modesto Irrigation District	3,411,342.6	646.1
Metropolitan Water District of Southern California	1,069,073.4	202.5
Oroville-Wayandotte Irrigation District	153,068.7	29.0
Pacificorp	5,063,886.5	959.1
PG&E	100,934,777.8	19,116.4
Plumas –Sierra Rural Electric Corp., Inc.	597,162.9	113.1
Redding Electric Dept.	331,744.5	62.8
San Francisco City and County	3,672,670.1	695.6
Southern California Edison	62,089,137.4	11,759.3
San Diego Gas and Electric	8,808,941.4	1,668.4
Shasta Dam Area Public Utility District	65,275.2	12.4
Sierra Pacific Power Company	1,072,240.6	203.1
Sacramento Municipal Utility District	4,960,669.4	939.5
Surprise Valley Electrification Corp.	596,625.8	113.0
Turlock Irrigation District	2,221,015.6	420.6
Western Area Power Administration	7,735,193.7	1,465.0
Total	**227,794,646.5**	**43,142.9**

The main result is that only about 6-8% or 2,500 circuit miles pass through residential areas. We estimate that the 900 miles of lower voltage class transmission lines are single circuit and that the remaining 1,600 miles are double circuit. Since double circuit lines carry two circuits on each pole or tower, there will be 800 structure miles of double circuit lines plus 900 structure miles of single circuit lines, totaling 1,700 structure miles. Assuming about 50 residences per mile on each side of the line, 170,000 homes would be affected. If each home has three residents, 510,000 people in California would live close to transmission lines and would potentially be exposed to high fields.

Table 2.3: Percentage of Land Use by Voltage Class
(Shaded: Developed Land Uses)

Voltage Class (kV) / Use Class Description	34-59	60-92	110-161	220-287	345-500	>500	Total Land (mi^2)
Bare exposed rock	0.00%	0.00%	0.00%	0.38%	0.14%	0.88%	0.6
Bays and Estuaries	0.00%	1.01%	2.82%	1.83%	0.00%	0.00%	2.4
Commercial and services	0.00%	1.78%	0.53%	1.84%	2.71%	0.00%	2.9
Confined feeding operations	0.00%	0.09%	0.00%	0.01%	0.00%	0.00%	0.0
Cropland and pasture	2.24%	26.82%	23.18%	19.61%	16.33%	0.96%	38.0
Deciduous forest land	0.00%	1.33%	0.23%	2.21%	5.29%	0.00%	3.9
Dry Salt Flats	0.00%	0.00%	0.00%	0.00%	0.00%	0.20%	0.1
Evergreen Forest Land	41.03%	25.90%	19.05%	13.70%	12.90%	28.59%	60.0
Forested wetland	0.00%	0.00%	0.17%	0.06%	0.00%	0.00%	0.1
Herbaceous Rangeland	2.25%	7.48%	4.94%	11.76%	3.65%	1.09%	13.3
Industrial	0.00%	0.94%	2.08%	1.27%	0.52%	0.00%	2.1
Lakes	0.47%	0.00%	0.51%	0.04%	1.46%	0.00%	1.1
Mixed forest land	0.72%	1.63%	5.59%	4.95%	1.63%	0.41%	6.4
Mixed Rangeland	7.38%	1.76%	2.85%	2.70%	3.81%	11.80%	12.9
Mixed urban or built-up land	0.00%	0.13%	0.10%	0.21%	0.00%	0.00%	0.2
Nonforested wetland	0.00%	1.15%	0.04%	0.90%	0.00%	0.15%	1.0
Orchards	0.00%	2.39%	7.69%	6.13%	1.27%	0.00%	7.5
Other agricultural land	0.00%	0.06%	0.04%	0.01%	0.15%	0.00%	0.1
Other urban or built-up land	0.00%	0.32%	1.74%	0.57%	1.09%	0.00%	1.6
Reservoirs	2.02%	0.59%	0.17%	0.64%	0.51%	0.00%	1.7
Residential	0.01%	5.96%	8.38%	5.96%	5.97%	0.00%	11.2
Sandy areas not beaches	0.00%	0.00%	0.19%	0.01%	0.41%	0.00%	0.3
Shrub and brush rangeland	26.83%	14.69%	18.62%	23.86%	41.41%	54.93%	76.7
Shrub and Brush Tundra	17.06%	0.00%	0.00%	0.00%	0.16%	0.84%	7.6
Streams and canals	0.00%	0.10%	0.00%	0.29%	0.38%	0.00%	0.3
Strip mines	0.00%	0.16%	0.12%	0.54%	0.05%	0.09%	0.4
Transitional areas	0.00%	1.03%	0.35%	0.13%	0.06%	0.00%	0.7
Transportation	0.00%	0.62%	0.59%	0.40%	0.10%	0.05%	0.8
Unknown	0.00%	4.05%	0.00%	0.00%	0.00%	0.00%	1.7
Total Land Area (mi^2)	42.1	42.8	42.6	42.7	42.6	42.6	255.2

Table 2.4 shows the distribution of census characteristics in the 500 ft. buffer area of the power lines by voltage class. The largest population and population density was found near voltage class 60-92 kV, with a population of 35,514 and a population density of 879 persons per square mile. The lowest population and population density was found near voltage class 34-59 kV, with a population of 348 and a population density of 8.4 persons per square mile.

The average percentage Black population was low in all voltage classes, with less than 4% of the population. Average percentage Hispanic population ranged from 6 – 21% of the population, with the highest in voltage class 345-500 kV. Average median household income ranged from $26,000-39,000 annually, with the highest income in the

220-287 kV class. This class (220-287 kV) also had the highest average median property value ($183,302).

Table 2.4: Census Data within 500 Feet of the Samples Transmission Lines Segments

Voltage Class	Estimated Population	% Black	% Hispanic	Population Density (persons/sq mi)	Average Median Household Income	Average Median Property Value
2 (34-59 kV)	347.69	0.38%	6.78%	8.443	$28,081.33	$123,885.66
3 (60-92 kV)	35,513.46	2.27%	21.66%	878.744	$34,707.82	$156,029.29
4 (110-161 kV)	20,374.57	3.36%	17.89%	497.147	$35,566.61	$151,493.90
5 (220-287 kV)	22,552.34	3.01%	19.98%	563.637	$39,282.91	$183,302.32
6 (345-500 kV)	1,621.68	3.63%	24.21%	43.545	$31,751.36	$128,348.18
7 (500 kV)	1,180.81	3.90%	11.21%	29.086	$26,885.85	$81,516.20

Overall, the results indicate that the residential land uses near transmission lines are relatively rare (between 0 and 8%), that blacks are under-represented near transmission lines (around 3% vs. 7.4% state-wide), that Hispanics are under-represented as well (between 7% and 22% vs. 25.4% state-wide), that the median household income is comparable (between $27,000 and $39,000 vs. $36,000 state-wide), and that the property values are lower near transmission lines (between $81,000 and $183,000 vs. $195,000 state-wide).

2.2 Distribution Lines

In developed areas, distribution lines are everywhere. Consequently, it is much more difficult to obtain a clear statewide picture of the land use and population characteristics near distribution lines. Data provided by five investor-owned utilities (PG&E, SCE, SDG&E, Pacificorp, and Sierra Pacific), separating distribution lines into primary vs. secondary lines and overhead vs. underground lines, are shown in Table 2.5. In this data, only PG&E separated primary and secondary distribution lines (approximately 50% each).

Table 2.5: California Utilities' Distribution Lines in Miles
(IOU stands for Investor-Owned Utilities)

		OH	UG
Primary	IOUs	124,493	39,255
	All	159,606	50,327
Secondary	IOUs	127,361	40,617
	All	163,283	52,073
Total	IOUs	251,854	79,872
	All	322,890	102,400

OH: Overhead lines
UG: Underground cable

The investor-owned utilities serve approximately 78% of all customers in California (California Energy Commission, 1999; website www.energy.ca.gov). Assuming that the length of the distribution lines increases linearly with the number of customers and that the remaining utilities have the same proportion of underground and overhead lines, we extrapolated the length of the California distribution line system to the numbers shown in the last row of Table 2.5.

Because distribution lines are everywhere, it is very difficult to obtain good estimates of how many miles of these lines can potentially affect fields in homes. High fields are mostly due to the primary overhead distribution lines. Lee et al. (2001) provide a limited data set on exposures from several sources, including transmission lines, distribution lines, and grounding systems. This data set describes a random sample of homes in a largely suburban area of Northern California. Table 2.6 shows the number of homes by wire code and the percentage of homes that exceeded a time-weighted average (TWA) reading of 2 mG, depending on wire code. The number of people affected were calculated by multiplying the California population of 33 million with the percentage shown in the column "% in Code and > 2mG."

Table 2.6: Classification of Homes in California by Wire Code and EMF Exposure
(Source: Lee et al., 2001, sample size: 611 homes, Northern California)

Wire Code	Sources	% of Homes in Code	% above 2 mG	% in Code and > 2 mG	People > 2 mG
Very High	Transmission and Distribution	12.5%	15.0%	1.9%	618,750
Ordinary High	Distribution and Grounding	23.3%	9.3%	2.2%	715,077
Ordinary Low	Distribution and Grounding	26.8%	7.3%	2.0%	645,612
Underground	Grounding	37.4%	5.0%	1.9%	617,100
TOTAL		**100%**	**7.9%**	**7.9%**	**2,596,539**

Because of the possibility that two or more sources contribute to exceeding 2 mG, it is difficult to attribute the number of people exposed to more than 2 mG to a single source. For example, some "very high" wire code lines are transmission lines. Yet, some transmission lines have underbuilt distribution lines and removing the transmission line may leave an elevated exposure from the distribution line. Even removing the distribution line might leave fields from improper grounding.

We separated out the sources by making some reasonable assumptions. First, we assumed that all of the lower voltage transmission lines with 900 miles in residential areas are located street side and have underbuilt distribution lines. Thus, about half of the transmission lines also have distribution lines that may cause exposures above 2 mG to about 310,000 people. Second, we assumed that distribution lines and home grounding systems are independent sources of exposure. According to Table 5 about 7% of all exceedances above 2 mG are due to either home grounding or distribution lines. From Zafanella (1993), we estimate that about 5% of homes have field above 2 mG due to home grounding systems alone. Using these assumptions, we estimate that about two percent or 670,000 people in California's are exposed to 2 mG or more due to distribution lines in the absence of transmission lines. Adding the 310,000 people from underbuilt distribution line exposure, we estimate close to 1,000,000 people to have exposures above 2 mG from distribution lines overall. For each mile of distribution lines that produce fields above 2 mG, we estimated that there are 50 affected homes with 3 residents each. By dividing a million people by 150 people per mile we estimate that there would be about 6,700 miles of distribution lines that produce fields above 2 mG.

2.3 Home Grounding Systems

Grounding systems in homes are used to divert fault currents produced by short circuits or electrical malfunctions to reduce electrocution risk and fire hazards. The National Electric Code (NEC) requires homes to be grounded to the main water pipe and to a metal grounding rod that is driven into the earth near the electric utility service panel (National Fire Protection Association, 1990). It also requires the neutral wire from the service drop to be connected to the ground. Return currents produced by loads in the home may split between the service drop neutral wire, the water pipe, and the grounding rod. The currents are inversely related to the impedance of the respective return path. The service neutral will likely have the lowest impedance and thus the highest current.

Copper and galvanized steel water pipes have low impedances and provide an opportunity for high currents to flow to and through the water main. Grounding rods have the highest impedance, and as a consequence carry the least current.

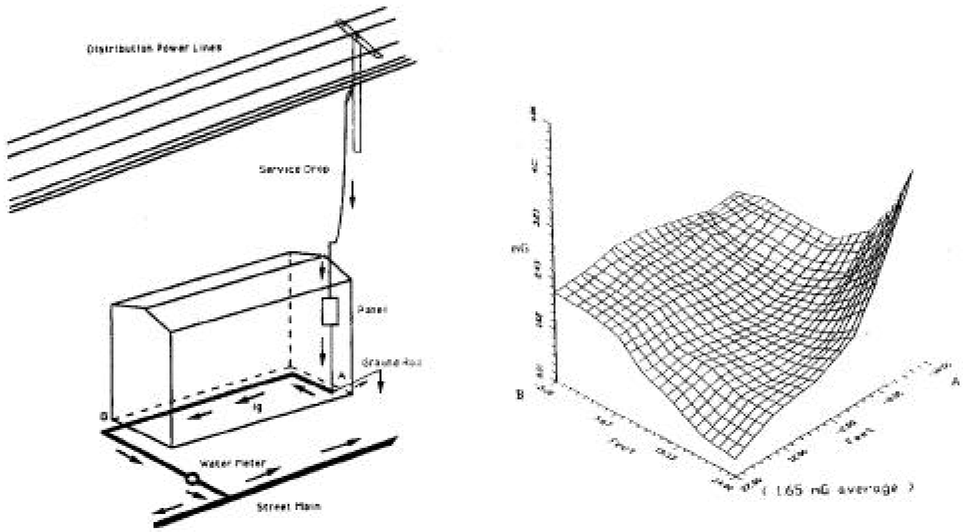

Figure 2.3: Typical Magnetic Fields in a Home
(from von Winterfeldt and Trauger, 1996)

If the service neutral is corroded, or otherwise not functioning as an effective return path, the current on the water pipe can be quite high, producing a magnetic field that is proportional to the current and inversely proportional to the distance from the pipe. Figure 2.3 shows a typical home with a service drop at the back of the house and the water main at the front (left panel). The right panel of Figure 2.3 shows the magnetic fields produced by the current on the water pipe. The fields are highest (5 mG) near the service panel (Figure 2.3, point A) and they are about 2 mG along the path of the water pipe (between points A and B).

Average spot measurements in U.S homes show a median value of 0.6 mG (Johnson, 1991; Zafanella, 1993). Average magnetic fields from grounding systems exceeded 1 mG in 9.3% of the surveyed houses and exceeded 2.5 mG in 2.5% of the houses. Thus, grounding systems can contribute to elevated fields in between 2.5% and 10% of homes. We used 5% as a base estimate, resulting in 1,650,000 people exposed to elevated fields due to home grounding systems.

2.4 Substations

There are about 2,300 substations in the California electric utility grid (California Energy Commission, 1999, website: www.energy.ca.gov). Many of these facilities have very high fields in their close vicinity. However, the fields drop off rapidly with increasing distance. Unlike fields from line sources, which drop off with roughly the square of distance, fields from point sources like substations drop off with the cube of the distance.

The original proposal by Decision Insights, Inc. had envisioned a special policy analysis module for substations. However, workshops with decision-makers and stakeholders (see Chapter 3) revealed less interest in substations than in power lines. Furthermore, the policy options regarding substations are quite limited. For new substations the obvious policy option is to develop siting and land use restrictions. For existing substations, there are very few inexpensive options to reduce the fields. As a result, the project did not analyze substations. Instead, more intensive efforts on power lines were undertaken.

2.7 Summary of Exposures from Different Sources

Table 2.7 summarizes the sources of elevated exposure to EMFs, the associated miles or homes, as appropriate, and the exposed population.

Table 2.7: Estimates of Sources (Miles of Powerlines or Homes) and People Exposed to 2 mG or More

Source	Miles/Homes	Population Exposed > 2 mG
Transmission	1,700 miles	510,000
Distribution	6700 miles	1,000,000
Home Grounding	550,000 homes	1,650,000
TOTAL*		**2,596,539**

*The total number of exposed people estimated by Lee et. al (2001) is smaller than the sum of the number of people affected by each source, because of an overlap between sources.